# HEAT TRANSFER ANALAYIS OF FLAT- PLATE SOLAR WATER HEATER WITH PHASE CHANGE MATERIALS

**S. Ramasamy**

*Lecturer in Mechanical Engineering, Government Polytechnic College, Melur, Tamilnadu, India.*

**Dr. T. Louie Frango**

*Professor & Head of Mechanical Engineering, Sri Vidya College of Engg . and Tech.,Virudhunagar,*

***Abstract***

*Solar energy has greatest potential of all the sources of renewable energy. It is one of the most important supplies of energy especially when other sources of supply in the country have depleted. In particular, solar energy, being non-polluting, clean, free of cost and inexhaustible, has received wide attention among scientists and engineers. Hence some form of thermal energy storage (TES) is necessary for the most effective utilization of this solar energy source. Thermal energy can be stored in form of sensible heat or latent heat or combination of sensible and latent heat. Storage of solar energy as a sensible energy is cheap but inefficient, due to its low storage density, low specific heat of heat transfer fluid, etc. On the other hand, latent heat storage (LHS) concept, which involves storing and recovering heat through the solid-liquid phase change process and vice versa., has advantages of high heat storage capacity and isothermal behavior during charging (heat storage) and discharging (heat release) processes. The present work has been undertaken to study the feasibility of storing solar energy using Phase Change Materials (PCMs).*

*In this research work, two conventional solar flat plate solar water heaters, storage tank with and without phase change materials was fabricated to investigate the feasibility and heat transfer analysis of storing solar energy with and without phase change materials (PCMs) and also studied energy storage capacity of storage tanks. For this study, organic phase change material had selected due to its thermal characteristics. This stored energy are used to heat water for domestic applications during night time. The performance of this PCM based thermal energy storage system is going to compare with conventional sensible heat storage system. The experiment was conducted with different types of flow rates and verify with energy storage time period in the evening hours and also analysis the cumulative heat stored capacity.*

***Key Words*****:** *Thermal energy storage, Phase change material, Sensible Heat (SH), Latent Heat (LH), Flat plate solar water heater*

## Introduction

Solar energy is the origin of all known forms of energy. Fossil fuels such as oil, coal, and natural gas were produced by photosynthetic processes, after that, complex chemical reactions took place and the decaying vegetation was subjected to very high temperatures and pressures for a long time. In addition, the sun produces the wind energy because wind is produced as a result of the difference in temperature between the various regions of the earth. Solar energy can be converted into different forms of energy, either to thermal energy or to electrical energy. Solar energy is converted directly into electrical power only by photovoltaic; photovoltaic is a device that converts the direct solar radiation into direct electrical current. On the other hand, solar collector converts solar energy into thermal energy. The solar collector is a device that absorbs the direct solar radiation and converts it into thermal energy.

Energy storage not only reduces the mismatch between supply and demand but also improves the performance and reliability of energy systems and plays an important role in energy conservation. It leads to save fuels and makes the system cost effective by reducing wastage of energy. One of the prospective storing thermal energy is the application of phase change materials (PCMs). In SHS system, thermal energy can be stored in the form of sensible heat in which energy stored by raising the temperature of storage material solid or liquid. Rock or water is the best example of SHS systems. Alternatively, thermal energy can be stored as latent heat in which energy is stored when a substance changes from one phase to another phase by either melting or freezing. The temperature of substance remains constant during phase change. Latent heat thermal energy storage technique has proved better option due to its high storage capacity with smaller temperature difference between storage and retrieval. Phase change materials are materials which use chemical bonds to store and release heat energy in the process of charging and discharging. The objective of the present work is to do heat transfer analysis in flat-plate solar water heater with and without phase change materials and also to study storage capacity of phase change materials.

## Solar Water Heater

Solar water heater is a device that helps in heating water by using the energy from the son. This energy is totally free solar energy (sun rays) is used for heating water. Water is easily heated to a temperature of 60-80□. solar water heater of 100-300 liter capacity are suited for domestic use larger system can be used in restaurants, canteens ,guest houses, hotels hospitals etc. A hundred liter capacity SWH can replace and electric geyser for residential use and may save up to 500 unit of electricity annually .The use of 1000 SWH of 100 liter capacity is can contribute to a peak load saving of approximately 1MW. A SWH of 100 liter capacity can prevent emission of 1.5 tons of $CO_2$ per year. [1,2] energy input for space heating or cooling are more specific examples. [1, 2]

## Working of a Solar Water Heater

The Sun's rays fall on the Collector Panel (a component of Solar Water Heater). A black absorbing surface (absorber) inside the collector absorbs solar radiation and transfers the heat energy to water flowing through it. Heated water is collected in a tank which is insulated to prevent heat loss. Circulation of water from the tank through the collector and back the tank continues automatically due to thermo-siphon principle.

## Types of Solar Water Heater

Passive systems rely on the natural buoyancy or thermosyphon effect created when the temperature of the water in the collector rises, causing the water itself to rise as it becomes less dense with increased temperature, thus inducing circulation in the circuit. Solar thermal systems in their simplest form consist of a solar collector and a storage tank. These systems are termed passive, whilst those that contain circulating pumps are known as active systems. The active closed loop and open loop solar water heater was shown in figures1 and 2.

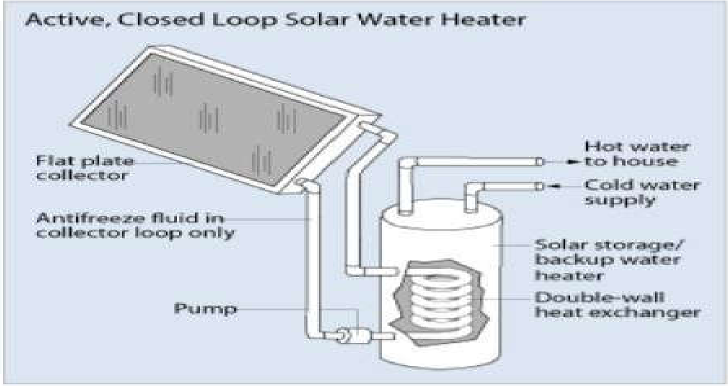


**Figure 1 Active, Closed Loop Solar Water Heater**

Solar water heating or solar hot water is water heated by the use of solar energy a solar heating system are generally composed of solar thermal collectors, a fluid system to move the heat from the collector to its point of usage the system may use electricity for pumping the fluid, and have a reservoir or tank of heat storage and subsequent use. The system may be use to heat water for a wide variety of uses, including home business and industrial uses, the heating swimming pools under floor heating

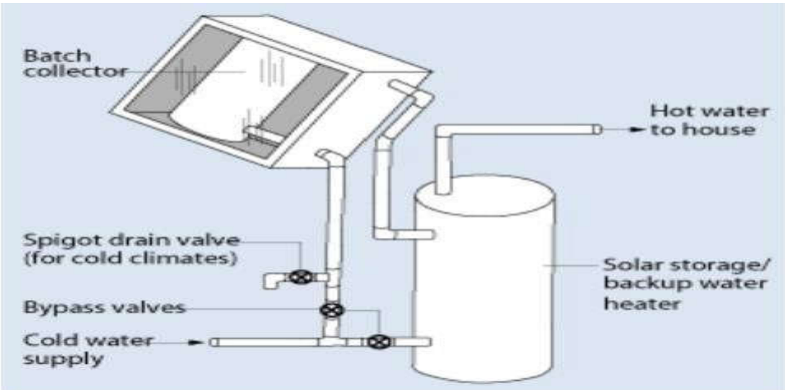


**Figure 2 Active Open Loop System Solar Water Heater**

**Flat-Plates Collector**

Flat Plate collectors are designed to heat water to medium temperatures (approximately 140 degree Fahrenheit): Enclosure: A box or frame that hold all the components together. Glazing: A transparent cover over the enclosure that allows the sun's rays to pass through to the absorber. Most glazing is glass but some design use clear plastic. Glazing Frame: Glazing gasket prevent leakage around the glazing frame and allows for contraction and expansion. Insulation: Material between the absorber and the surface it touches that blocks heat loss by conduction there by reducing the heat loss from the collector enclosure. Absorber: A flat. Usually metal surface inside the enclosure that, because of its physical properties, can absorbs and transfer high levels of solar energy. Flow Tube:

Highly conductive metal tubes across the absorber through which fluid flows, transferring heat from the absorber to the fluid. [1, 2]

**Integral Collector Storage (ICS) System**

In other solar water heating systems the collector and storage tank are separate components .In an integral collector storage (ICS) system ,both collection and solar storage are combined within a single unit. The entire unit is exposed to solar energy throughout the day. The resulting water is drawn off either directly to the service location or as replacement hot water to an auxiliary storage tank as water is drawn for use. Cold water flow progressively through the collector was it is heated by sun. Hot water drawn from the top which is the hottest, and replacement water flow in to the bottom this system is simple because pump and controls are not required .On demand, cold water from the house flows in the collector and hot water from the collector flow to a standard hot water auxiliary tank within the house. [6]

**Phase Change Materials (PCMs)**

All materials are phase change materials. The most important difference between these materials is the phase change temperature. Each material makes its phase change at different temperature. In addition, each material has a different value of latent heat and thermal conductivity. The main drawback of most of phase change materials is their low thermal conductivity that decreases the heat transfer rate. The most important feature for the selected phase change material is to have its phase change temperature fitted to the application temperature range. Indeed, there is no specific material that is called as an ideal material to be used as a phase change material. Energy storage is the most fundamental requirement of all solar energy systems. [4, 6]

No material has all the optimal characteristics for a PCM, and the selection of a PCM for a given application requires careful consideration of the properties of various 20,000 compounds and/or mixtures have been considered in PCM, including single component systems, congruent mixtures, and tactics. The isothermal operating characteristics (i.e. Charging/discharging heat at a nearly constant temperature) during the solidification and melting processes, which is desirable for efficient operation of thermal systems [4, 6, 9, 10]. Phase change materials offer the best solution to this fundamental requirement, thereby resolving the problem met during the time of peak demand. The phase change material is shown in figures 3.

**Figure 3 PCM Material**

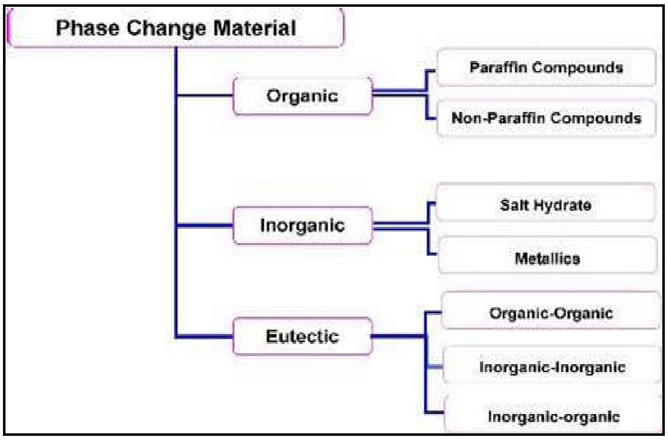


**Figure 4 Classification of Phase Change Materials**

**Paraffin**

Paraffin of type $C_nH_{2n+2}$ is a group of saturated hydrocarbons with very similar properties, Paraffin between C5 and C15 are liquids and the rest are waxy solids, Paraffin wax is one of the most popular organic heat storage PCM for commercial applications, it consists of a straight chain hydrocarbon having melting temperatures ranging between 23□and 67□. [3, 5, 10]

**Non-Paraffin**

The non-paraffin organic PCMs are characterized by their varied properties; each of these materials has its own properties. These organic materials are subdivided into fatty acids and other non-paraffin organic.

**Inorganic Phase Change Materials**

Inorganic phase change materials are classified as salt hydrates and metallic [3, 5, 10]

**Salt Hydrates**

Salt hydrates consist of a salt and water that combine in a crystalline matrix when the material solidifies. There are many different salt hydrates having melting temperature ranges between 15°C - 117°C, Salt hydrates are considered as the most important group of PCMs that have been studied for application in latent thermal energy storage systems.

**Metallic**

Metallic include the low melting metals and metal eutectics. Metallic have not been strongly studied as PCM for latent heat storage because of their heavy weights. For the applications that weight is not an important issue while volume is an important parameter, metallic are attractive because of their high heat of fusion per unit volume.

**Experimental Investigations**

In this application, unlike solar water heater, the cold water is supplied to the solar water heater and the hot water is stored in a tank in which PCM balls are placed. Due to the higher temperature PCM starts to melt. Generally PCM materials require a fluid with 5 higher than its freezing temperature to melt them. [8, 9, 10] Thus collected energy is stored in the form of latent heat of PCM as well as hot water which is also present in the same storage tank.

In this experiment, A thermal energy storage tank (TES) was designed with and without phase change materials to do heat transfer analysis in the of LHS system. The schematic of the experimental setup is shown in Figure5. It consists of the cylindrical TES tank of size 360 mm and 648 mm height which consists of PCM in a packed bed of spherical PVC capsules, solar flat plate collector, flow meter, temperature indicator and a circulating pump. The stainless steel TES tank has a capacity of 100 liters capable of supplying water for a family consists of seven members at an average temperature of 38-45° C. It contains spherical PCM capsules of diameter 75 mm which contains organic salt as a phase change materials. It contains two plenum chambers on the top and the bottom of the tank and a flow distributor is provided on the top of the tank to maintain a uniform flow of HTF. The tank is insulated with 20 mm of glass wool and is provided with an aluminum cladding. It is considered that, on an average, the family would require 100 liters of heated water for their daily needs. This energy is stored as a mixture of sensible and latent heat of PCM and sensible heat of water within the TES tank. We assume that the PCM store two-thirds of the energy while the remaining is stored as sensible heat of water. The PCM used in the experiment is OM 48 and material of the spherical capsules used in the experiments is high density polyethylene (HDPE). The TES tank is divided into three segments; that is, at / = 0.3, 0.6, and 0.9 ( is length of the TES tank, mm; is the axial distance from the top of the TES tank, mm; / is the dimensionless axial distance from the top of the TES tank) along its axial direction; the resistant temperature detectors(RTDs) with an accuracy of ± 0.3ºC are placed at the inlet, outlet, and three segments of the TES tank to measure the temperatures of HTF. Another six numbers of RTDs are inserted into the PCM capsules and they are placed at six segments of the TES tank to measure the temperatures of PCM. The RTDs are connected to a temperature indicator, which provides instantaneous digital outputs. A flow meter with an accuracy of ±2% is used to measure the flow rate of HTF and a centrifugal pump (500 lit/hour) is employed to circulate the HTF through the storage tank. The performance of the charging of TES is studied using 2 lit/min, and 4 lit/min flow rates with varying inlet HTF temperatures.

**Experimental Setup**

Figures 5 show the schematic diagram and photographic view of the experimental setup developed for the investigation.

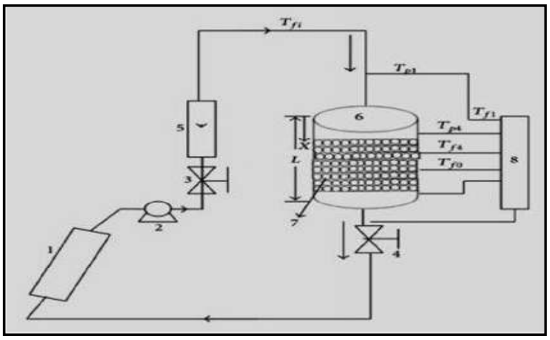

**Figure 5 Experimental Setup**

Figure 5 shows the Schematic of the experimental setup (1) solar flat plate collector, (2) pump, (3) and (4) flow control valves, (5) flow meter, (6) TES tank, (7) PCM capsules, and (8) temperature indicator, , and :temperature sensors (RTDs). The performance of the charging of TES is studied using 2 lit/min and 4 lit/min flow rates with varying inlet HTF temperatures. Initially, the energy is stored inside the capsules as sensible heat until the PCM reaches its melting temperature. As the charging process proceeds, energy storage is achieved by melting the PCM at a constant temperature. Finally, the PCM becomes superheated. The energy is then stored as sensible heat in liquid PCM. Temperatures of the PCM and HTF are recorded at an interval of 12 minutes. The charging process is continued until the PCM temperature reaches the value of 61 $^{o}$C.

Batch wise discharging [4,7] of TES is studied with different discharge flow rates, that is, 2 lit/min and 4 lit/min keeping the constant cold water inlet, that is, 2 lit/min and 30 $^{o}$ C. A certain quantity of hot water (6.67 lit) is withdrawn from TES tank and the tank is again filled with cold water of quantity equal to the amount of water withdrawn. Again, after a time interval of 15 minutes, allowing transfer of energy from PCM to HTF, another 6.67 lit of water is withdrawn from the TES tank. This process is continued until the water (HTF) outlet temperature reaches 34$^{\circ}$C.The table 1 shows the design specification of solar water heater and Table 2 shows the thermo physical properties of PCM.

**Table 1 Design Specifications**

| | Parameters | Specifications |
|---|---|---|
| 1 | Material for collector | Stainless steel |
| 2 | Length of the collector | 2m |
| 3 | Width of the collector | 1m |
| 4 | Area of the collector | $2m^2$ |
| 5 | Air gap between glass plate and Collector | 5cm |
| 6 | Total quantity of PCM | 11kg |
| 7 | Material of PCM balls | High density polyethylene |
| 8 | PCM Ball Dia | 75 mm |
| 9 | Approx PCM capacity | 0.180 litre/ball |
| 10 | Tank capacity | 100 litres |

**Table 2 Thermo Physical Properties of PCM (OM 48)**

| S. | Parameters | Properties Value |
|---|---|---|
| 1 | Freezing Temp (C) | 48 |
| 2 | Melting Temp (C) | 46 |
| 3 | Latent Heat (kJ/kg) | 275 |
| 4 | Liquid Density (kg/m3) | 0.875 |
| 5 | Solid Density (kg/m3) | 0.98 |
| 6 | Liquid Specific Heat (J/kgk) | 2.3 to 2.4 |
| 7 | Solid Specific Heat (J/kgk) | 1.8 to 1.9 |
| 8 | Congruent melting | Yes |
| 9 | Description | Mixture of organic materials |
| 10 | Appearance | White waxy solid below 48 |

**Results and Discussions**

The following readings and graphs were prepared based on the observations taken for consecutive ten days in the month of April 2019. Out of those readings, the readings on 28/04/2019 were shown for the flow rate of 2 kg/min with and without PCMs.

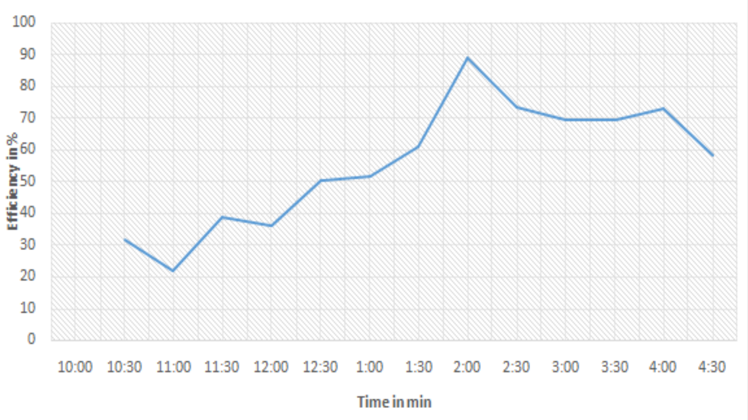


**Figure 6 Time Vs. Efficiency**

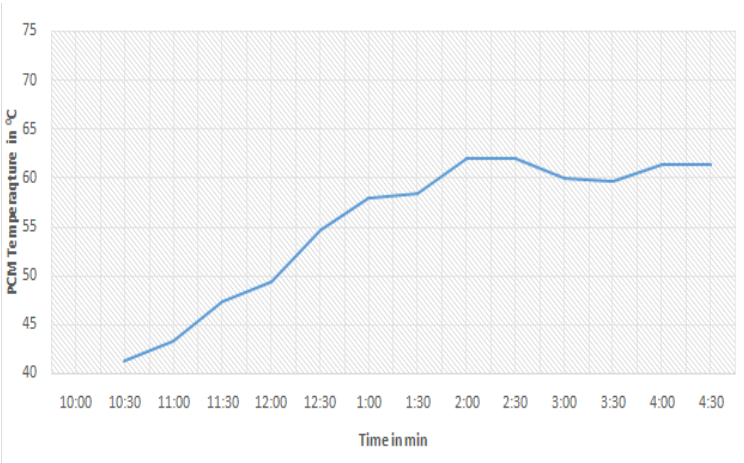


**Figure 7 Time Vs. PCM Temperature**

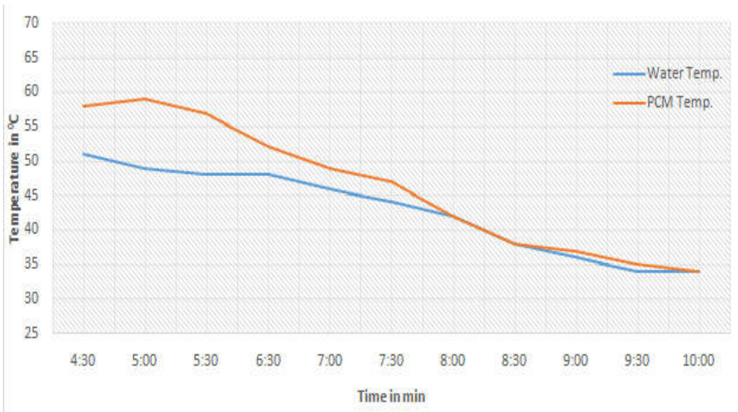


**Figure 8 Time Vs. PCM Temperature and Water Temperature**

**Conclusion**

- The performance of the solar collector can be enhanced by increasing the area of the absorber plate and increasing the size of the water tubes.
- The performance of solar water heater with PCM can be improved by selecting the appropriate PCM with high thermal storage capacity.
- The performance of absorber plate can be enhanced by fixing at better orientations.
- It is also improved by increasing the quantity of PCM and also heat transfer area.
- The mass flow rate has significant effect on the heat extraction rate from the solar collector, which in turn affect the rate of charging of the TES tank.
- Combined sensible and latent storage concept reduces the size of storage tank appreciably compared to conventional storage system.
- The combined heat storage system employing batch wise discharging of hot water from the TES tank is best suited for applications where the requirement is intermittent.

**References**

1. G.D Rai., Non-Conventional Energy Sources, Fifth ed., Khanna Publishers, New Delhi, 2011.
2. D.P.Kothari, K.C.Singal, Kakesh Ranjan., Renewable Energy Sources and Emerging Technologies, Seconded., PHI Learning Private Limited, New Delhi- 2011.
3. Farid M, Khudhair AM, Razack SAK, Al-Hallaj S., A review on phase change energy storage: materials and applications. Energy Conversion Management 2004; 45:1597–615.
4. Nallusamy, N, Sampath B, Velraj R., Experimental investigation on a combined sensible and latent heat storage system integrated with constant/varying (solar) sources, Renewable Energy, 2007; 32:1206-27.
5. S.A.Khot, N.K.Sane, B.S.Gawali., Thermal energy storage using PCM for solar domestic hot water system:Review, Journal of Eng.India Ser.C (April-June 2012) 93(2):171-176
6. F.B.A.Ami, Prof.A.M.Patil, Prof.H.M.Dange., Comparitive study of solar water heater with and witout latent heat storage system.,international journal of advanced engineering research and studies,E-ISSN 2249-8974,Vol II, Issue 3,April-June 2013
7. R.Meenakshi Reddy, N.Nallusamy,K.Hemachandra Reddy., The effect of PCM capsule material on the thermal energy storage system performace., Hindawi Publishing Corporation, ISRN Renewable Energy, 2014
8. Demirbas M.F., Thermal Energy Storage and Phase Change Materials: An Overview, Energy Sources, Part B, 2006, 1, p. 85–95.A. Sharma et al.: Review on thermal energy storage with phase change materials and applications. Renewable and Sustainable Energy Reviews, vol. 13, 2009, pp. 318-345.
9. Belen Zalba, Jose M Marin, Luisa F Cabeza, Harald Mehling., Review on thermal energy storage with phase change: materials, heat transfer analysis and applications., Applied thermal energy 23 (2003) 251-283